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Transport Lines for the NLC Damping Rings

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Abstract: The NLC damping ring designs have undergone significant changes in the past year. This note describes the current state of the designs for the transport lines carrying beam from the booster linacs into the damping rings and out of the damping rings into the bunch compressors. The functions, optics, and structural layout of the transport lines are described.

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Abstract

The NLC damping ring designs have undergone significant changes in the past year. This note describes the current state of the designs for the transport lines carrying beam from the booster linacs into the damping rings, and out of the damping rings to the bunch compressors. The functions, optics and structural layout of the transport lines are described.

1 Introduction

The NLC ZDR[1] presented designs for transport lines meeting the requirements of the damping rings also discussed in that report. Since then, the damping ring designs[2] have evolved in response to various changes in NLC parameters, and this has necessitated redesign of the transport lines. We conceptually break the transport lines down into six separate lines:

1. Electron main damping ring (EMDR) injection line;
2. EMDR extraction line;
3. Positron predamping ring (PPDR) injection line;
4. PPDR extraction line;
5. Positron main damping ring (PMDR) injection line;
6. PMDR extraction line.

Lines 4 and 5 (PPDR extraction and PMDR injection) actually form a single continuous structure. However, from point of view of design, and from functional and operational considerations, we prefer to refer to them separately. It may be the case, for example, that a beam dump will be included between the PPDR extraction and PMDR injection.

The transport lines have more functions than simply transporting the beam. Other systems that need to be included are:

- an arc in the PPDR injection and EMDR injection, as part of the energy compression and spin rotation systems;
- RF sections in the PPDR injection and EMDR injection for energy compression;
- solenoids in the PPDR injection, EMDR injection, PMDR extraction and EMDR extraction for spin rotation;
- bends for compensating jitter on the injection and extraction kickers and septa;
- diagnostics for emittance, energy spread etc.

Note that the current specification on the source is for an unpolarized positron beam. However, we include space for spin rotation in the positron transport lines, so as not to preclude an upgrade to a polarized source. Arcs are required in the PPDR injection and

PMDR extraction lines for other purposes, and we simply fix the bend angles to appropriate values for the spin rotation, should it be required.

2 Damping Rings and Transports General Layout

The EMDR and associated transports are shown in Figure 1, and the PPDR, PMDR and associated transports are shown in Figure 2. The lengths of the various beamlines are given in Table 1.

Table 1

Lengths of beamlines in the damping rings systems.

EMDR Injection	107.650 m
EMDR	299.792 m
EMDR Extraction	251.474 m
PPDR Injection	110.758 m
PPDR	230.933 m
PPDR Extraction	108.178 m
PMDR Injection	52.359 m
PMDR	299.792 m
PMDR Extraction	110.997 m
Total Transports	741.416 m
Total Beamline	1571.933 m

The injection and extraction lines for the main damping rings cross one another close to the ring. We have designed the layout such that there should be sufficient spacing between components to make the engineering of this area possible; a detail of the layout is shown in Figure 3. There may be issues respecting the fact that the injected and extracted beams will pass through each other; we have not so far studied these issues.

A detail of the extraction region for the PPDR is shown in Figure 4.

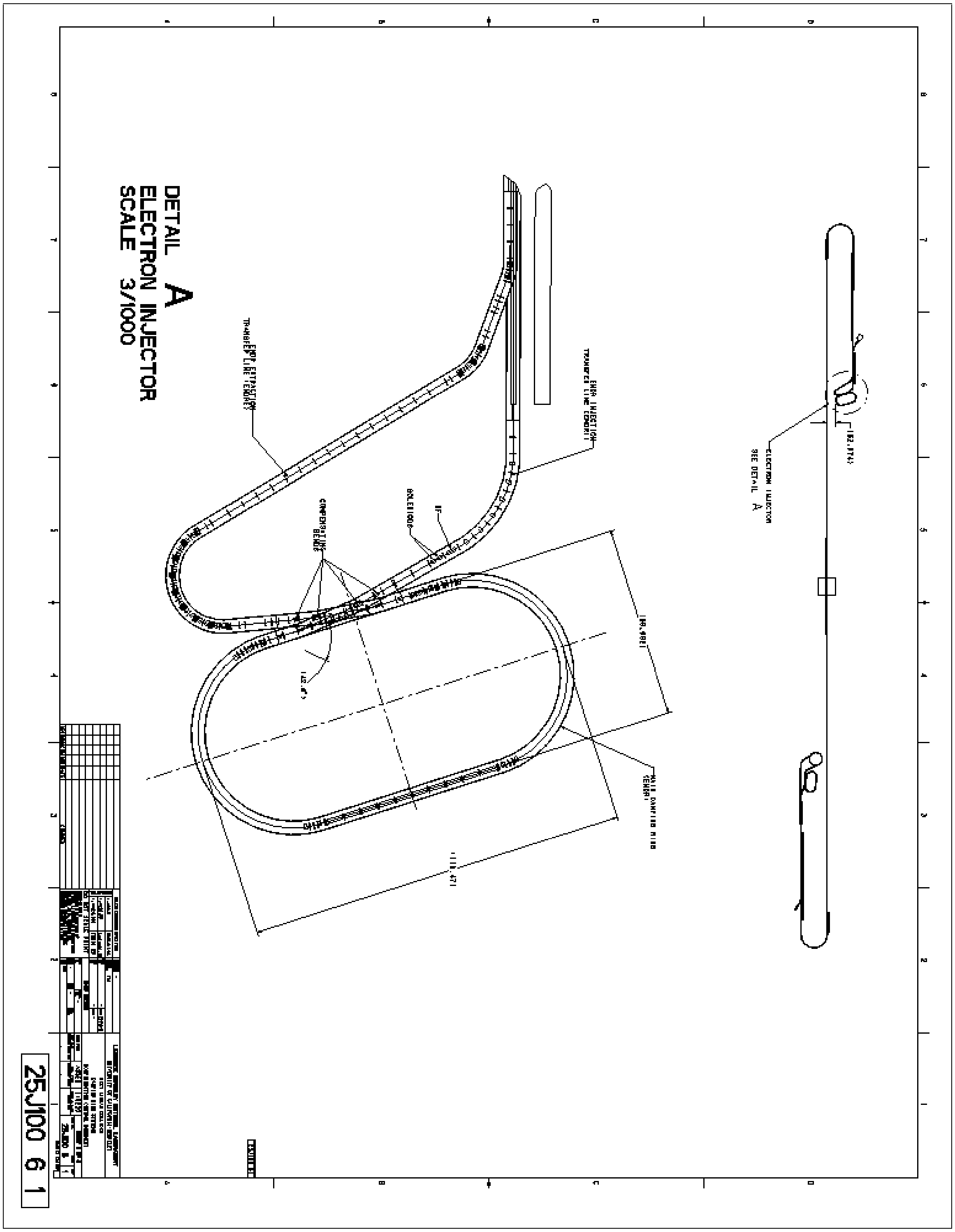

Figure 1

Layout of electron main damping ring and associated transport lines.

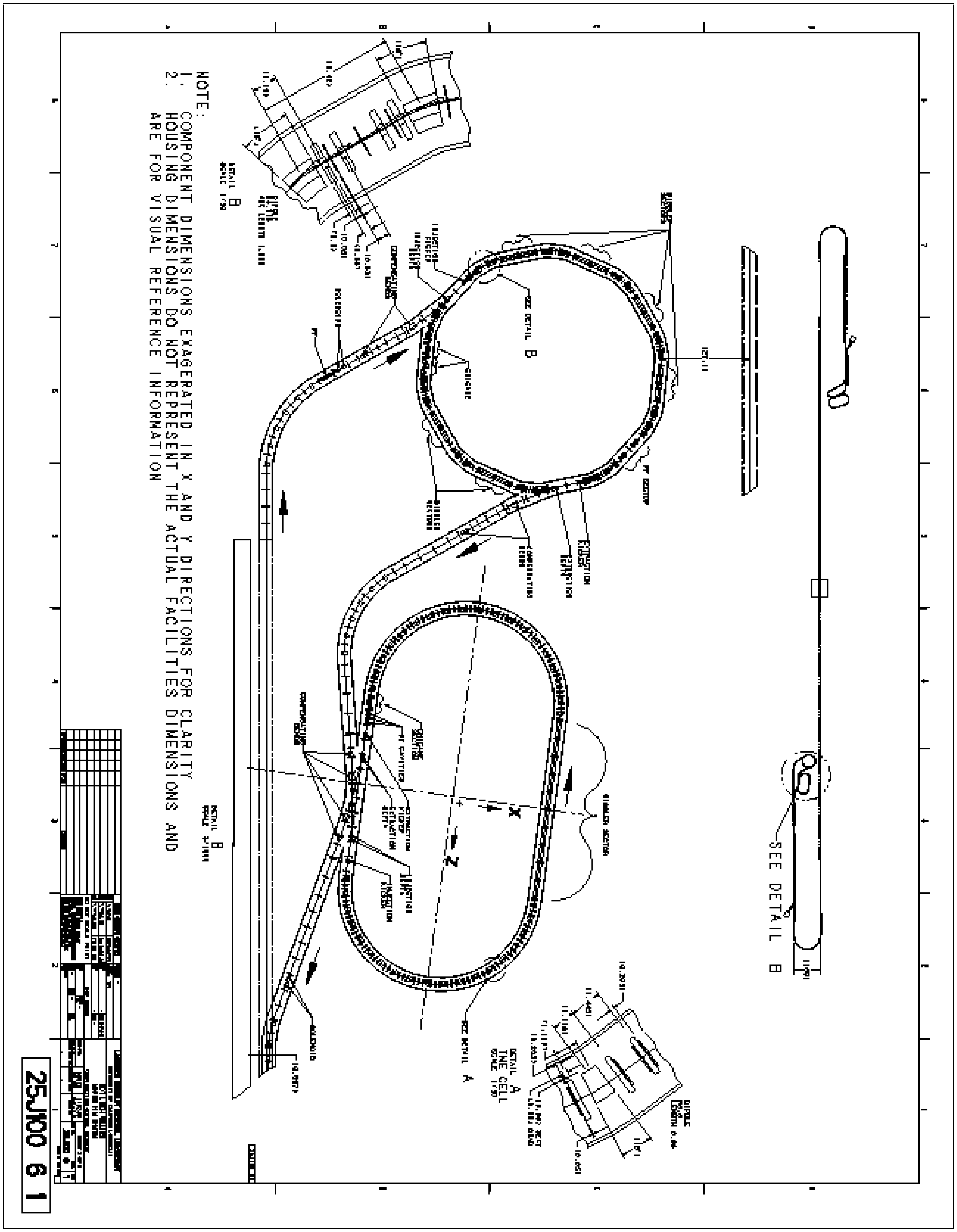

Figure 2

Layout of positron damping rings and associated transport lines.

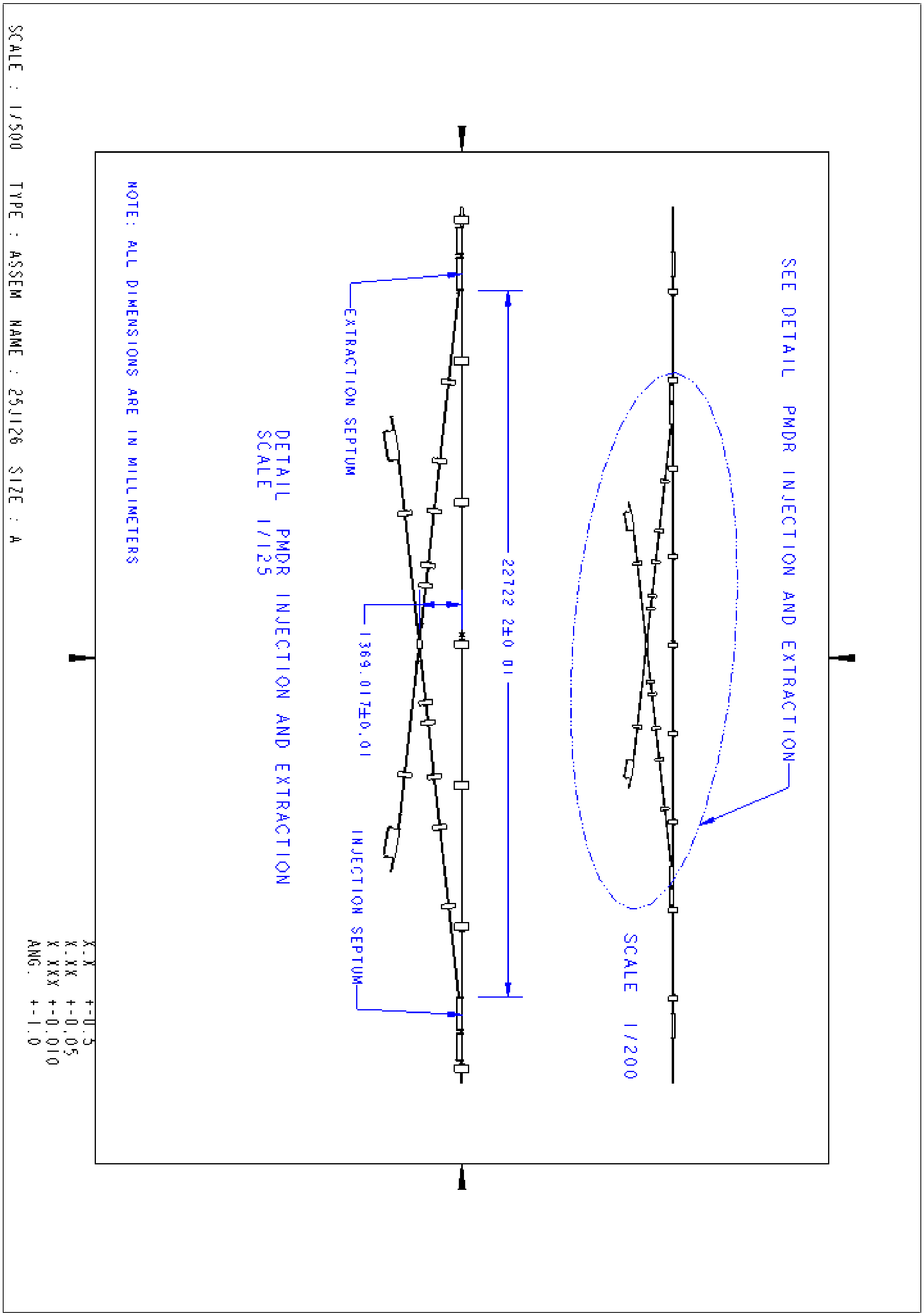

Figure 3

Intersection of injection/extraction lines near the main damping ring.

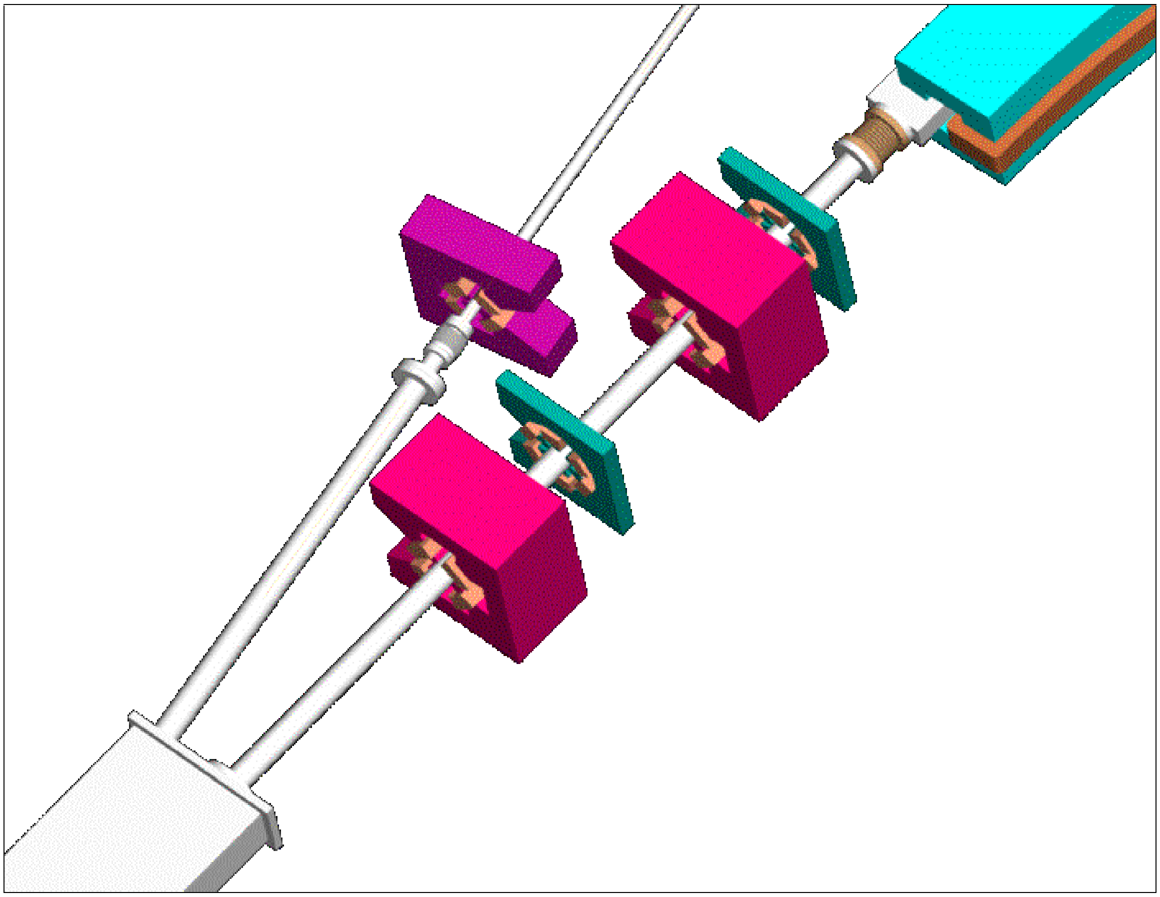

Figure 4

Detail of extraction region for PPDR. The extraction septum is seen in the lower left of the image, with the extracted beam passing to the left.

3 Systems Designs Considerations

3.1 Spin Rotation

It is assumed that the sources produce a longitudinally polarized beam, and that the energy is 1.98 GeV. To preserve polarization in the damping rings, the spin must be rotated into the vertical direction. This can be achieved using a horizontal arc to first rotate the spin into the horizontal direction, then using a solenoidal field to rotate the spin into the vertical.

For a particle with longitudinal polarization traveling with highly relativistic velocity through a vertical magnetic field, there is a simple relationship between the total spin precession angle Ψ and the total trajectory bend angle θ:

$$\Psi = \gamma \frac{g-2}{2} \theta$$

where g is the electron gyromagnetic constant, and γ is the relativistic factor. If we require the spin precession to be through 90° or 270°, then at 1.98 GeV, this fixes the bend angle at 20° or 60°. The arc on the injection line doubles in purpose in providing correlation between energy and position in the bunch for energy compression; a 60° arc is more effective for this purpose, so this angle has been chosen in the current design.

On the extraction side, the spin must be rotated back from the vertical direction to the longitudinal. This is accomplished with a 20° arc (plus solenoidal field) for both electrons and positrons.

The total precession angle of a transverse spin for a particle traveling through a longitudinal field of strength B_z and length l is given by:

$$\Psi = \frac{g}{2} \frac{B_z l}{B\rho}$$

where $B\rho$ is the beam rigidity. Thus, to rotate a transverse horizontal polarization to a vertical polarization, we need an integrated longitudinal field of 10.36 Tm. The ZDR design specifies two superconducting solenoids[3] with lengths of 1.5 m and fields of 3.46T, similar to the spin rotation solenoids in the SLC injection system. The present transport lines design maintains this specification.

3.2 Energy Compression

The positron source is specified to produce a beam with a full width energy spread of 2% within each bunch, and bunch-to-bunch energy variation of 1%. The RF acceptance of the PPDR is ±1.5%; thus, some energy compression is required between the positron booster linac and the PPDR. Although the electron source produces bunches with energy spread of only 1%, the bunch-to-bunch energy variation is 1%, and the RF acceptance of the EMDR is again ±1.5%. Energy compression will thus also be required for the electron beam before injection into the ring.

Table 2

Energy compressors parameters and effect on longitudinal distributions. The calculations of the energy spread and bunch length after the compressor are based on the transformation of the longitudinal phase space ellipse.

		Electron	Positron
Energy compressor parameters	R_{56}	1.11 m	1.11 m
	f_{RF}	2856 MHz	1428 MHz
	V_{RF}	42 MV	80 MV
Before compressor	Full width $\Delta E/E$	2.0 %	3.0 %
	Full width bunch length	10 mm	10 mm
After compressor	Full width $\Delta E/E$	1.2 %	1.7 %
	Full width bunch length	17 mm	20 mm

With the current injection line designs, the 60° arc produces an R_{56} transport matrix element of 1.11 m. We have taken the RF parameters from the ZDR[4]. These parameters, and the effects on the longitudinal phase space distribution, are given in Table 2. Note that the final distributions are based on a simple linear transformation of the longitudinal phase space ellipse; the phase space distributions produced by the source will be anything but elliptical, and more thorough tracking studies should be performed in the future. However, we do not expect the final values to vary significantly, and there is sufficient margin that significant revision to the design should not be necessary.

L-band RF structures have been chosen for the positron energy compressor, to provide a larger aperture for the high emittance beam produced by the source. 5 m of space are available for the RF sections in both the PPDR injection line, and in the EMDR injection line.

3.3 Diagnostics

Diagnostics have not recently been considered in detail, though there is a discussion in the ZDR[5]. In the current designs, there are a number of sections throughout the transport lines where it might be appropriate to locate diagnostic devices. For example, in the EMDR injection line, there is an 18 m FODO section between the spin rotators and the compensating bends, where emittance diagnostics could be installed. There is sufficient flexibility in the optics to adapt the lattice designs to the requirements of particular diagnostics, once these have been considered in more detail.

3.4 Compensating Bends

All injection and extraction lines include compensating bends to offset the effects of injection and extraction components in the damping rings. The compensating bends have two roles:

1. matching the dispersion generated by the kickers and septa;
2. easing the tolerances on field stability in the kickers and septa.

The first objective is achieved by setting the integrated field of the compensating bends as close as possible to those of the corresponding kickers and septa, and by appropriate optical design. The second objective is achieved by setting the horizontal phase advance between a component and its corresponding compensating bend to a half integer; and by having the same power supply or pulser feed each magnet. Thus, if a particle sees a larger than expected field in a kicker, for example, it will see an equally large field in the compensating kicker; but with a half-integer phase advance between the components, the effects will cancel. This is the same strategy as specified in the ZDR[6].

4 Transport Lines Optics

Beta functions and dispersion in the six transport lines are shown in Figure 5 through Figure 10.

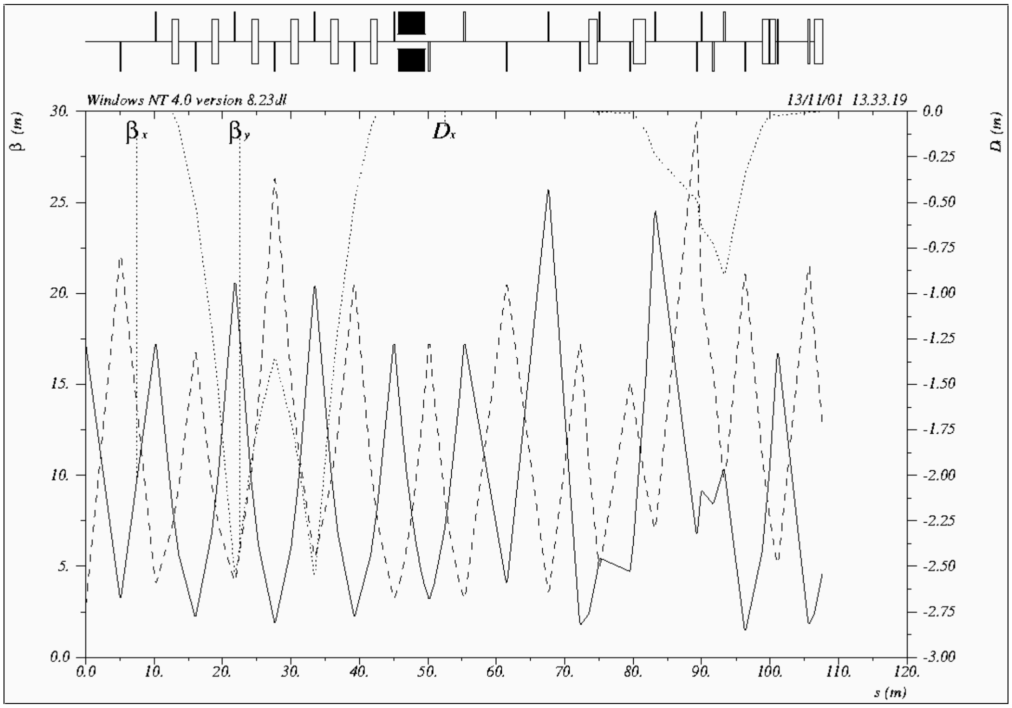

Figure 5

EMDR injection line optics. Systems include: (10 – 45 m) 60° arc; (45 – 50 m) S-band RF; (50 – 55 m) spin rotation solenoids; (55 – 73 m) diagnostics section; (73 – 82 m) compensating bends; (82 – 99 m) matching section; (99 – 107 m) injection components.

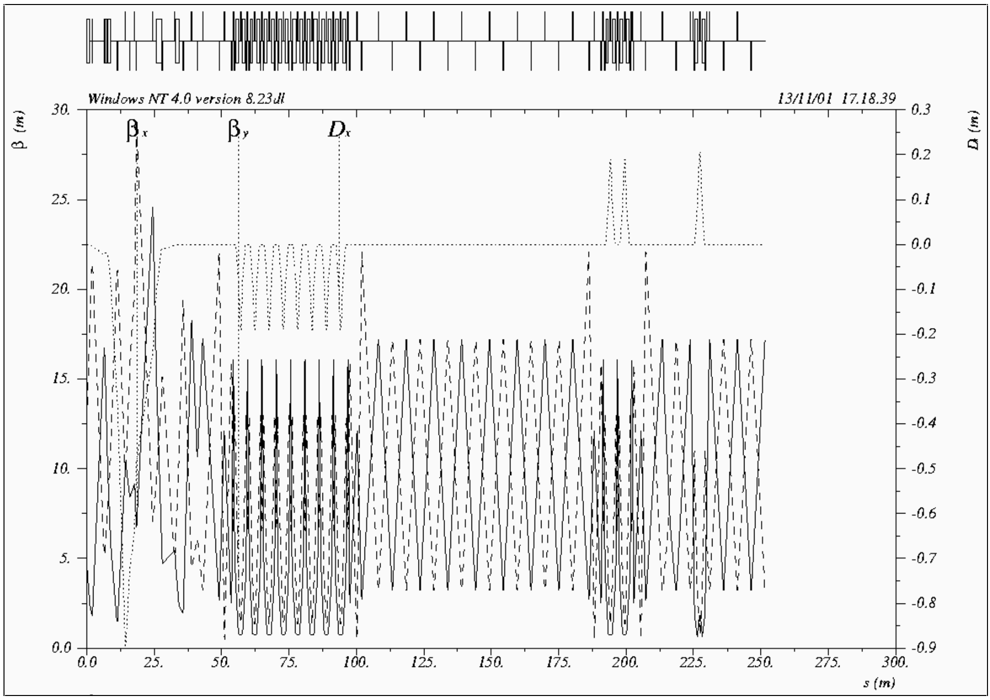

Figure 6

EMDR extraction line optics. Systems include: (0 – 9 m) extraction components; (9 – 25 m) matching section; (25 – 35 m) compensating bends; (214 – 218 m) spin rotation solenoids; (225 – 230 m) 20° arc.

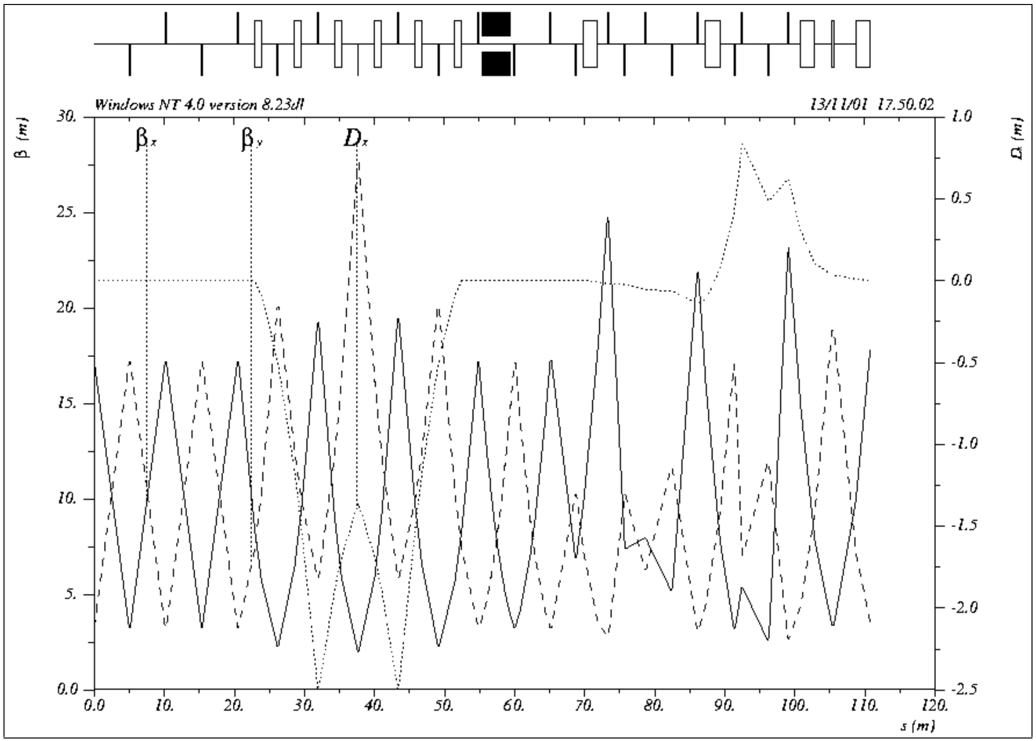

Figure 7

PPDR injection line optics. Systems include: (20 – 55 m) 60° arc; (55 – 60 m) S-band RF; (60 – 65 m) spin rotation solenoids; (70 – 90 m) compensating bends; (90 – 100 m) matching section; (100 – 111 m) injection components.

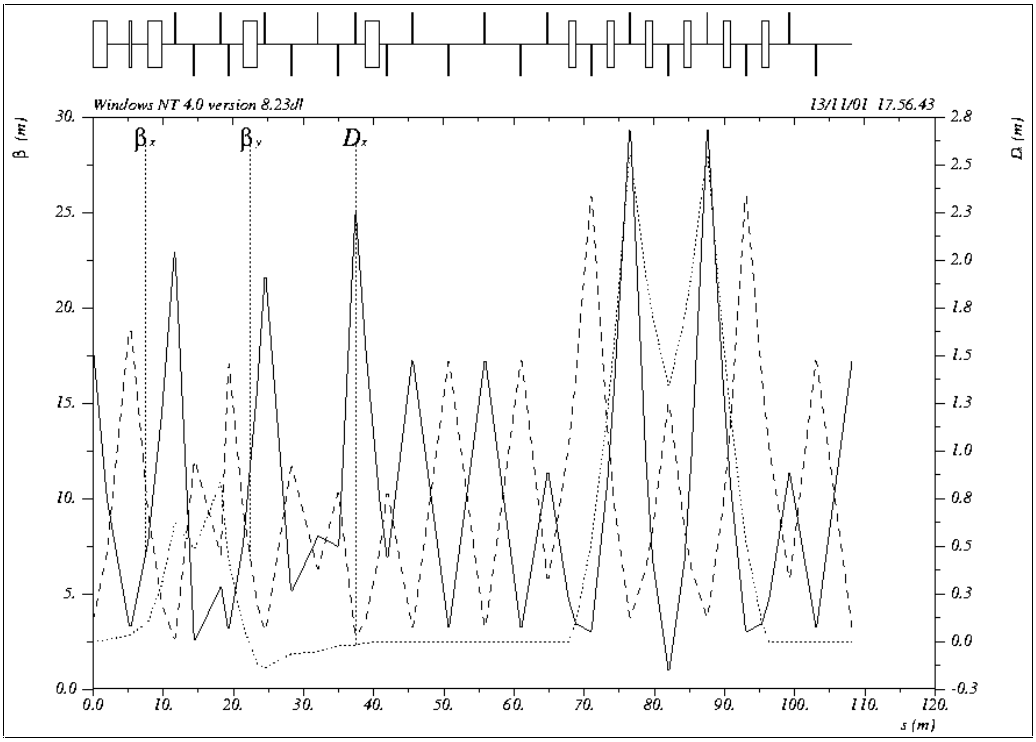

Figure 8

PPDR extraction line optics. Systems include: (0 – 10 m) extraction components; (10 – 20 m) matching section; (20 – 41 m) compensating bends.

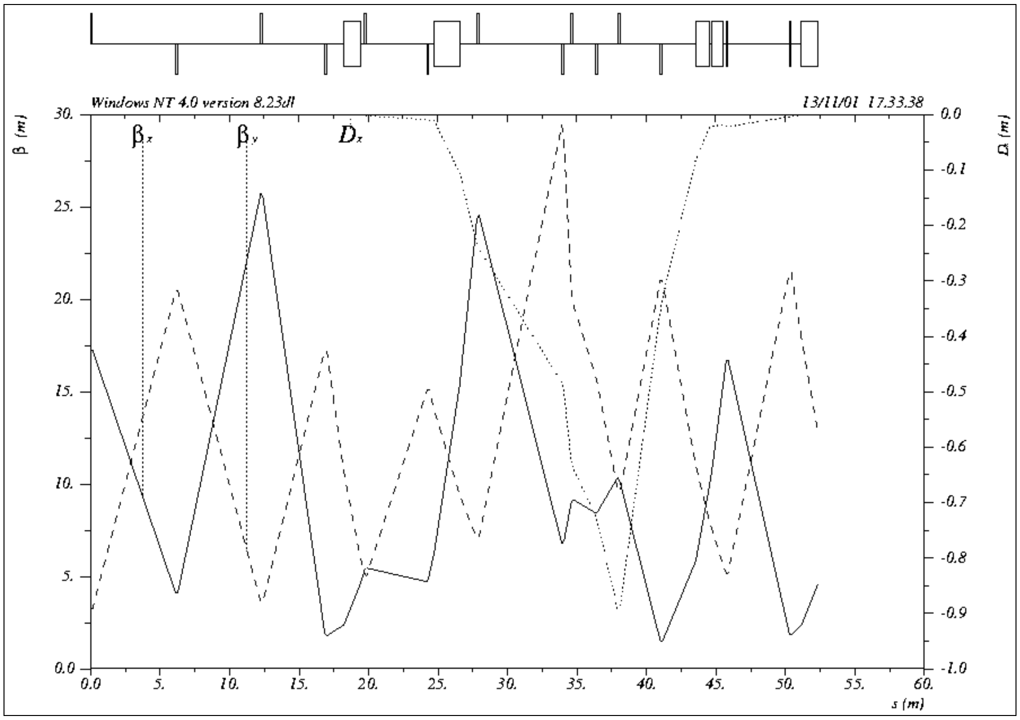

Figure 9

PMDR injection line optics. Systems include: (18 – 27 m) extraction components; (27 – 44 m) matching section; (44 – 53 m) injection components.

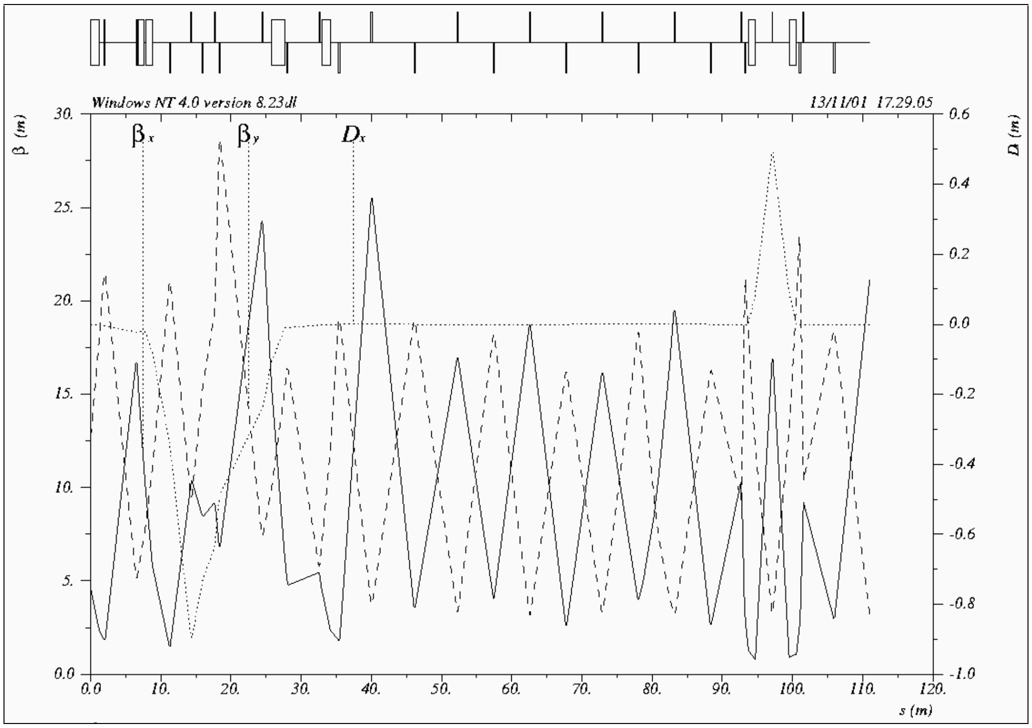

Figure 10

PMDR extraction line optics. Systems include: (0 – 10 m) extraction components; (10 – 25 m) matching section; (25 – 35 m) compensating bends; (79 – 83 m) spin rotation solenoids; (93 – 101 m) 20° arc.

5 Magnets and Vacuum System

Magnet specifications are given in Table 3 through Table 8; the units are metres, radians and tesla, as appropriate. Note that these specifications are given by beam optics considerations only, and no attempt has yet been made to minimize the number of different magnet styles. Note also that the various magnets designated CKCK are compensating bends for the injection/extraction kickers, and we expect these to be powered by the same pulser as the kickers themselves.

With a bunch population of 10^{10} particles, 190 bunches per train and a repetition rate of 120 Hz, the mean current in the transport lines will be 36.5 μA. We do not expect radiation loads to be such as to require cooled photon stops, and it is proposed at present that a straightforward round pipe will be used for the vacuum chamber. The ZDR[7] specifies a vacuum pressure below 10^{-8} Torr in the transport lines.

Table 3

Magnet specifications in the EMDR injection line.

Name	Type	Count	Length	Bend Angle	Normalized Gradient	Pole-tip radius	Pole-tip field
Q1	QUADRUPOLE	1	0.15	0	-0.234768	0.02	-0.0310108
Q11	QUADRUPOLE	1	0.15	0	-0.282626	0.02	-0.0373325
Q12	QUADRUPOLE	1	0.15	0	0.330458	0.02	0.04365065
Q13	QUADRUPOLE	1	0.15	0	-0.180337	0.02	-0.023821
Q14	QUADRUPOLE	1	0.15	0	0.317147	0.02	0.04189239
Q1A	QUADRUPOLE	2	0.15	0	-0.224819	0.02	-0.0296967
Q2	QUADRUPOLE	1	0.15	0	0.32675	0.02	0.04316086
Q2A	QUADRUPOLE	2	0.15	0	0.271206	0.02	0.03582398
Q3	QUADRUPOLE	1	0.15	0	-7.53E-02	0.02	-0.0099464
Q3A	QUADRUPOLE	1	0.15	0	-0.221467	0.02	-0.0292539
Q4	QUADRUPOLE	1	0.15	0	0.272362	0.02	0.03597667
Q5	QUADRUPOLE	1	0.15	0	-0.375089	0.02	-0.049546
Q6	QUADRUPOLE	1	0.15	0	0.254333	0.02	0.0335952
Q8	QUADRUPOLE	1	0.15	0	-0.215277	0.02	-0.0284362
Q9	QUADRUPOLE	1	0.15	0	0.387948	0.02	0.05124459
QFODOD	QUADRUPOLE	2	0.15	0	-0.27	0.02	-0.0356647
QFODOF	QUADRUPOLE	2	0.15	0	0.27	0.02	0.03566467
BB	SBEND	6	1	-0.174533	0	0.02	-1.1527153
CKCK	SBEND	1	1.2	-2.50E-03	0	0.02	-0.0137595
CSPT	SBEND	1	1.83	-9.72E-02	0	0.02	-0.3507697

Table 4

Magnet specifications in the EMDR extraction line.

Name	Type	Count	Length	Bend Angle	Normalized Gradient	Pole-tip radius	Pole-tip field
Q1	QUADRUPOLE	1	0.15	0	-0.234768	0.02	-0.031010829
Q11	QUADRUPOLE	1	0.15	0	-0.345576	0.02	-0.045647611
Q110	QUADRUPOLE	4	0.15	0	-0.59956	0.02	-0.079196709
Q12	QUADRUPOLE	1	0.15	0	0.3575	0.02	0.047222669
Q120	QUADRUPOLE	4	0.15	0	0.86396	0.02	0.11412167
Q13	QUADRUPOLE	1	0.15	0	-0.287191	0.02	-0.037935456
Q130	QUADRUPOLE	4	0.15	0	-1.06164	0.02	-0.140233494
Q14	QUADRUPOLE	1	0.15	0	0.251611	0.02	0.033235645
Q18	QUADRUPOLE	24	0.15	0	0.962043	0.02	0.127077589
Q19	QUADRUPOLE	20	0.15	0	-1.07352	0.02	-0.14180274
Q1A	QUADRUPOLE	1	0.3	0	1.61179	0.02	0.212903568
Q2	QUADRUPOLE	1	0.15	0	0.32675	0.02	0.043160859
Q21	QUADRUPOLE	10	0.25	0	1.70718	0.02	0.225503765
Q22	QUADRUPOLE	2	0.15	0	0.428284	0.02	0.056572625
Q23	QUADRUPOLE	2	0.15	0	0.610302	0.02	0.080615634
Q24	QUADRUPOLE	2	0.15	0	-1.08073	0.02	-0.142755119
Q3	QUADRUPOLE	1	0.15	0	-7.53E-02	0.02	-0.009946428
Q4	QUADRUPOLE	1	0.15	0	0.272362	0.02	0.035976673
Q5	QUADRUPOLE	1	0.15	0	-0.375089	0.02	-0.049546024
Q6	QUADRUPOLE	1	0.15	0	0.254333	0.02	0.033595197
Q8	QUADRUPOLE	1	0.15	0	-0.215277	0.02	-0.028436236
Q9	QUADRUPOLE	1	0.15	0	0.387948	0.02	0.051244587
QFODOD	QUADRUPOLE	10	0.15	0	-0.27	0.02	-0.035664673
QFODOF	QUADRUPOLE	10	0.15	0	0.27	0.02	0.035664673
BBA	SBEND	2	1	0.174533	0	0.02	1.152715256
BBM	SBEND	4	1	0.168504	0	0.02	1.112896309
BBP	SBEND	16	1	-0.168504	0	0.02	-1.112896309
CKCK	SBEND	1	1.2	-2.50E-03	0	0.02	-0.013759519
CSPT	SBEND	1	1.83	-9.72E-02	0	0.02	-0.350769747

Table 5

Magnet specifications in the PPDR injection line.

Name	Type	Count	Length	Bend Angle	Normalized Gradient	Pole-tip radius	Pole-tip field
Q1	QUADRUPOLE	1	0.15	0	0.367472	0.04	0.09707977
Q10	QUADRUPOLE	1	0.15	0	0.308236	0.04	0.08143064
Q12	QUADRUPOLE	1	0.15	0	-0.320028	0.04	-0.0845459
Q13	QUADRUPOLE	1	0.15	0	0.250318	0.04	0.0661297
Q1A	QUADRUPOLE	2	0.15	0	-0.223372	0.04	-0.059011
Q2	QUADRUPOLE	1	0.15	0	-0.298518	0.04	-0.0788633
Q2A	QUADRUPOLE	2	0.15	0	0.273027	0.04	0.07212903
Q3	QUADRUPOLE	1	0.15	0	0.571493	0.04	0.1509786
Q3A	QUADRUPOLE	1	0.15	0	-0.209523	0.04	-0.0553524
Q4	QUADRUPOLE	1	0.15	0	-0.479829	0.04	-0.1267626
Q6	QUADRUPOLE	1	0.15	0	0.286449	0.04	0.07567489
Q7	QUADRUPOLE	1	0.15	0	-0.257191	0.04	-0.0679454
Q8	QUADRUPOLE	1	0.15	0	0.13087	0.04	0.0345736
Q9	QUADRUPOLE	1	0.15	0	-0.321362	0.04	-0.0848983
QFODOD	QUADRUPOLE	3	0.15	0	-0.27	0.04	-0.0713293
QFODOF	QUADRUPOLE	3	0.15	0	0.27	0.04	0.07132935
BB	SBEND	6	1	-0.174533	0	0.04	-1.1527153
CKCK	SBEND	1	2	-8.00E-03	0	0.04	-0.0264183
CSPT150	SBEND	1	2	0.15	0	0.04	0.49534268

Table 6

Magnet specifications in the PPDR extraction line.

Name	Type	Count	Length	Bend Angle	Normalized Gradient	Pole-tip radius	Pole-tip field
Q1	QUADRUPOLE	1	0.15	0	0.367472	0.02	0.04853988
Q10	QUADRUPOLE	1	0.15	0	0.308236	0.02	0.04071532
Q12	QUADRUPOLE	1	0.15	0	-0.320028	0.02	-0.0422729
Q13	QUADRUPOLE	1	0.15	0	0.250318	0.02	0.03306485
Q1A	QUADRUPOLE	2	0.15	0	-0.223073	0.02	-0.029466
Q1AM	QUADRUPOLE	2	0.15	0	0.298915	0.02	0.0394841
Q2	QUADRUPOLE	1	0.15	0	-0.298518	0.02	-0.0394317
Q2A	QUADRUPOLE	2	0.15	0	0.285726	0.02	0.03774194
Q2AM	QUADRUPOLE	2	0.15	0	-0.259957	0.02	-0.0343381
Q3	QUADRUPOLE	1	0.15	0	0.571493	0.02	0.0754893
Q3A	QUADRUPOLE	1	0.15	0	-0.242985	0.02	-0.0320962
Q4	QUADRUPOLE	1	0.15	0	-0.479829	0.02	-0.0633813
Q6	QUADRUPOLE	1	0.15	0	0.286449	0.02	0.03783744
Q7	QUADRUPOLE	1	0.15	0	-0.257191	0.02	-0.0339727
Q8	QUADRUPOLE	1	0.15	0	0.13087	0.02	0.0172868
Q9	QUADRUPOLE	1	0.15	0	-0.321362	0.02	-0.0424492
QFODOD	QUADRUPOLE	1	0.15	0	-0.27	0.02	-0.0356647
QFODOF	QUADRUPOLE	1	0.15	0	0.27	0.02	0.03566467
BB	SBEND	6	1	0.188457	0	0.02	1.24467728
CKCK	SBEND	1	2	-8.00E-03	0	0.02	-0.0264183
CSPT150	SBEND	1	2	0.15	0	0.02	0.49534268

Table 7

Magnet specifications in the PMDR injection line.

Name	Type	Count	Length	Bend Angle	Normalized Gradient	Pole-tip radius	Pole-tip field
Q1	QUADRUPOLE	1	0.15	0	-0.234768	0.02	-0.0310108
Q11	QUADRUPOLE	1	0.15	0	-0.314207	0.02	-0.041504
Q12	QUADRUPOLE	1	0.15	0	0.288458	0.02	0.03810282
Q13	QUADRUPOLE	1	0.15	0	-0.23849	0.02	-0.0315025
Q14	QUADRUPOLE	1	0.15	0	0.244829	0.02	0.0323398
Q2	QUADRUPOLE	1	0.15	0	0.32675	0.02	0.04316086
Q3	QUADRUPOLE	1	0.15	0	-7.53E-02	0.02	-0.0099464
Q4	QUADRUPOLE	1	0.15	0	0.272362	0.02	0.03597667
Q5	QUADRUPOLE	1	0.15	0	-0.375089	0.02	-0.049546
Q6	QUADRUPOLE	1	0.15	0	0.254333	0.02	0.0335952
Q8	QUADRUPOLE	1	0.15	0	-0.215277	0.02	-0.0284362
Q9	QUADRUPOLE	1	0.15	0	0.387948	0.02	0.05124459
CKCK	SBEND	1	1.2	-2.50E-03	0	0.02	-0.0137595
CSPT	SBEND	1	1.83	-9.72E-02	0	0.02	-0.3507697

Table 8

Magnet specifications in the PMDR extraction line.

Name	Type	Count	Length	Bend Angle	Normalized Gradient	Pole-tip radius	Pole-tip field
Q1	QUADRUPOLE	1	0.15	0	-0.236073	0.02	-0.0311832
Q11	QUADRUPOLE	1	0.15	0	-0.309038	0.02	-0.0408213
Q12	QUADRUPOLE	1	0.15	0	0.293811	0.02	0.0388099
Q13	QUADRUPOLE	1	0.15	0	-0.235876	0.02	-0.0311572
Q14	QUADRUPOLE	1	0.15	0	0.239857	0.02	0.03168304
Q1A	QUADRUPOLE	1	0.15	0	0.70006	0.02	0.09247189
Q1AM	QUADRUPOLE	2	0.15	0	-0.934223	0.02	-0.1234028
Q2	QUADRUPOLE	1	0.15	0	0.32674	0.02	0.04315954
Q2AM	QUADRUPOLE	2	0.15	0	1.15766	0.02	0.15291691
Q3	QUADRUPOLE	1	0.15	0	-7.60E-02	0.02	-0.0100337
Q3AM	QUADRUPOLE	2	0.15	0	-0.203662	0.02	-0.026902
Q4	QUADRUPOLE	1	0.15	0	0.270803	0.02	0.03577074
Q5	QUADRUPOLE	1	0.15	0	-0.370057	0.02	-0.0488813
Q6	QUADRUPOLE	1	0.15	0	0.252327	0.02	0.03333022
Q8	QUADRUPOLE	1	0.15	0	-0.209269	0.02	-0.0276426
Q9	QUADRUPOLE	1	0.15	0	0.38536	0.02	0.05090273
QFODOD	QUADRUPOLE	3	0.15	0	-0.27	0.02	-0.0356647
QFODOF	QUADRUPOLE	3	0.15	0	0.27	0.02	0.03566467
BB	SBEND	2	1	0.174533	0	0.02	1.15271526
CKCK	SBEND	1	1.2	-2.50E-03	0	0.02	-0.0137595
CSPT	SBEND	1	1.83	-9.72E-02	0	0.02	-0.3507697

6 Future Development

The present designs meet the first order optical requirements. Major systems for spin rotation and energy compression are included, as are the compensating bends for easing tolerances on the injection/extraction components. There are no apparent engineering obstacles.

Issues that need to be considered in the future include:

- requirements for diagnostics, particularly for emittance measurements;
- effects of the crossing between injected and extracted beams for the main damping rings;
- possible emittance dilution from bends in the electron extraction line.

7 References

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[1] NLC Design Group, “Zeroth-Order Design Report for the Next Linear Collider”, SLAC-PUB-5424, May 1996.

[2] A. Wolski, “Lattice Description for NLC Main Damping Rings at 120 Hz”, LCC-0061, April 2001. A.Wolski, “A New Structure for the NLC Positron Pre-Damping Ring Lattice”, LCC-0066, June 2001.

[3] ZDR, page 152.

[4] ZDR, pages 150-151.

[5] ZDR, page 150.

[6] ZDR, page 244.

[7] ZDR, page 217.